APPENDIX I. USGCRP MEMBER AGENCIES

This section summarizes the principal focus areas related to global change research for each USGCRP member agency.

Department of Agriculture

Global change research is fully integrated across the Department of Agriculture, involving multiple mission areas and including contributions from the Agricultural Research Service (ARS), the National Institute of Food and Agriculture (NIFA), the Forest Service (USDA-FS), Natural Resources Conservation Service (NRCS), National Agricultural Statistics Service (NASS), and Economic Research Service (ERS). These USDA entities ensure sustained food security for the Nation and the world. They maintain and enhance the health of U.S. forests and natural resources while identifying risks ranging from temperature and precipitation extremes to the changing infestation ranges and intensities of pests, invasive species, and diseases that result from shifting climatic conditions.

USDA assesses climate change effects on the natural and economic systems associated with productive lands. USDA develops cultivars, cropping systems, and management practices to improve drought tolerance and build resilience to climate variability. USDA promotes integration of USGCRP research findings into farm and natural resource management and helps build resiliency through the development of information products and decision-support tools.

USDA observes and monitors natural resource conditions on-the-ground. USDA assessments of natural resource conditions include the Long-Term Agro-ecosystem Research (LTAR) Network, the Snowpack Telemetry (SNOTEL) network, the Experimental Forests and Ranges, the Soil Climate Analysis Network (SCAN), the National Resources Inventory (NRI), and the Forest Inventory and Analysis (FIA) Program, which are utilized by multiple scientific and programmatic efforts across the Department and the U.S. Government to improve land management efforts.

USDA's ten Regional Climate Hubs deliver timely and authoritative tools and information to natural resource management professionals, ensuring that the latest science is available to support decision-making. To that end, USDA engages in many communication, outreach, education, and extension efforts across multiple forums to ensure that decision-makers, natural resource managers, and stakeholders have access to the most up-to-date scientific information for management decisions. The Hubs are an example of close interagency collaboration on climate change at the regional level, delivering tools, strategies, management, and technical solutions to farmers, ranchers, forestland owners, and resource managers to inform better decision-making in a changing climate.

Department of Commerce

The National Oceanic and Atmospheric Administration (NOAA) and the National Institute of Standards and Technology (NIST) comprise the Department of Commerce's (DOC's) participation in USGCRP.

NOAA's mission is to understand and predict changes in climate, weather, oceans and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources. From supercomputers and state-of-the-art models to observations and outlooks, NOAA provides data, tools, and information to help people understand and prepare for climate variability and change. NOAA's current priorities are (1) to reduce the impact of extreme weather and water events (Weather Act of 2017) and (2) to increase the sustainable economic contributions of our fishery and ocean resources (Blue Economy). NOAA aims to advance its goals and priorities through the following research and development vision areas:

- Reduced societal impacts from severe weather and other environmental phenomena;
- Sustainable use of coastal and ocean resources;
- A robust and effective research, development, and transition enterprise.

NIST's measurement science research supports enhanced, internationally accepted, and traceable measurement standards, methodologies, and technologies that provide accurate greenhouse gas emissions and uptake data and analyses to support mitigation management and the advancement of climate science research. NIST provides measurements and standards for consistent, comparable, and reliable climate observations and provides calibrations and special tests to improve the accuracy of a wide range of instruments and techniques used in climate research and monitoring.

Department of Defense

The Department of Defense (DoD) recognizes that global changes in the environment, such as climate change, impact DoD operations and installations. In alignment with the National Defense Strategy (NDS), the DoD Directive 4715.21 Climate Change Adaptation and Resilience, and the Department's 2019 Arctic Strategy, DoD seeks to understand, prepare, and respond to the impact of global environmental changes. DoD's research, development, test, and evaluation (RDT&E) activities as well as interagency and international collaboration through the USGCRP play a critical role in DoD's efforts to address global environmental change. DoD manages and executes RDT&E activities across the Services that respond to specific national security requirements and may also be leveraged to address the strategic goals of the USGCRP. DoD's global change RDT&E efforts focus on building awareness of the changing operational physical environment through observations and predictive models and enhancing operations in those changing environments via mitigation, adaptation, and resilience.

The Navy is exploring new platforms for sustained observational capability in the Arctic as well as developing global weather, ocean, and sea ice prediction models at the seasonal (months) timescale. The Navy and the Air Force collaborate with U.S. interagency partners on the National Earth System Prediction Capability, the next generation of predictive models for the entire Earth system. The Air Force leverages National and allied partners' seasonal and climate model projections to provide value-added products for DoD and the Intelligence Community. DoD is expanding and modifying an Army tool for installations to assess exposure to climate and weather impacts. The Army continues to focus on addressing Arctic mobility and infrastructure challenges. The Strategic Environmental Research and Development Program (SERDP), the Department's joint environmental science and technology program, invests in research to enhance DoD's overall resilience to environmental threats and climate change impacts. Finally, the Department more broadly sponsors basic research in a number of potentially relevant areas such as marine meteorology, physical oceanography, polar science and engineering, biogeochemical sciences, and terrestrial science and phenomenology.

Department of Energy

The Department of Energy's (DOE) Office of Science supports fundamental research to address key uncertainties in regional to global-scale Earth system change arising from the interactions and interdependencies of the atmospheric, terrestrial, cryospheric, oceanic, and human-energy components of the Earth system. DOE's research strives to understand and anticipate how environmental and compounding stressors can influence the pattern and magnitude of weather and other extremes, and how these in turn influence the robustness and resilience of U.S. energy infrastructures. Supporting its major role in Earth system prediction, DOE supports long-term field experiments to advance process and systems level understanding; scale-aware parameterizations that can be incorporated into multi-scale models; and advanced software tailored to models that can be ported to DOE's fastest supercomputers. DOE also invests novel machine learning and uncertainty quantification methodologies that allow model products to be more useful to DOE stakeholders. To assist the scientific community in carrying out research, DOE commits significant resources to archiving and management of extensive observed and model-generated datasets for easy retrieval and processing.

There are three areas of DOE research that contribute to the Department's efforts to advance the science of Earth system change: (a) Atmospheric System Research (science of aerosols, clouds, precipitation, and radiative transfer); (b) Terrestrial Ecosystem Science (role of terrestrial ecosystems and coupled biogeochemical cycles); and (c) advanced modeling that combines development, simulation and analysis. DOE maintains its own suite of advanced modeling platforms, including the Energy Exascale Earth System Model (E3SM), which currently uses DOE's advanced high performance pre-exascale computers; DOE also collaborates with NSF to support the widely used Community Earth System Model. Using the DOE-supported Program for Climate Model Diagnosis and Intercomparison (PCMDI) and the DOE- and NASA-supported Earth System Grid Federation, DOE analyzes and distributes large Earth System Model output, with data analytics capabilities available to researchers. The Department also supports the Atmospheric Radiation Measurement (ARM) Research Facility, a scientific user facility based on three permanent observatories and three mobile observatories that in turn provides the research community with unmatched measurements permitting the most detailed high-resolution, three-dimensional documentation of evolving cloud, aerosol, precipitation, and radiative transfer characteristics in climate-sensitive sites around the world.

DOE also conducts related applied research involving energy technologies, energy analysis, and prototype infrastructures. The research and analyses undertaken by these offices often requires the development and application of companion models to those used in the Office of Science, e.g., models of energy systems and infrastructures; economics; technology impact; and risk assessment. The applied offices also maintain and update datasets to explore such topics as electric grid stability, water availability for energy production, and siting of energy infrastructure.

Department of Health and Human Services

The U.S. Department of Health and Human Services (HHS) supports a broad portfolio of research and decision support initiatives related to environmental health and the health effects of global climate change, primarily through the National Institutes of Health (NIH) and the Centers for Disease Control and Prevention (CDC). Research focuses on the need to better understand the vulnerabilities of individuals and communities to climate-related changes in health risks such as heat-related morbidity and mortality, respiratory effects of air contaminants affected by climate change, changes in transmission of infectious diseases, and impacts in the aftermath of severe weather events, among many others. Research efforts also seek to assess the effectiveness of various public health adaptation strategies to reduce climate vulnerability, as well as the potential health effects of interventions to reduce GHG emissions.

Specifically, HHS supports USGCRP by conducting fundamental and applied research on linkages between climate variability and change and health, translating scientific advances into decision support tools for public health professionals, conducting ongoing monitoring and surveillance of climate-related health outcomes, and engaging the public health community in two-way communication about climate change.

Department of the Interior

The U.S. Geological Survey (USGS) conducts global change research for the Department of the Interior (DOI) and constitutes DOI's formal participation in USGCRP.

USGS scientists work with other agencies to provide policy makers and resource managers with scientifically valid information and an understanding of global change and its impacts with the ultimate goal of helping the Nation understand, adapt to, and mitigate global change.

Specifically, the USGS supports research to understand the physical, chemical, and biological components of the Earth system, the causes and consequences of climate and land use change, and the vulnerability and resilience of the Earth system to such changes. The USGS Land Change Science and National Land Imaging programs (such as the Landsat satellite mission and the National Land Cover Database) provide data that are used to assess changes in land use, land cover, ecosystems, and water resources resulting from the interactions between human activities and natural systems.

USGS also leads the regional DOI Climate Adaptation Science Centers, which deliver science to help fish, wildlife, water, land, and people adapt to a changing climate.

Department of State

The Department of State (DOS) contributes to the Intergovernmental Panel on Climate Change (IPCC), which assesses scientific, technical, and socioeconomic information relevant to the understanding of climate change, its potential impacts, and options for adaptation and mitigation. DOS, with the assistance of USGCRP, coordinates U.S. reviews of IPCC reports to ensure that the reports are a comprehensive, objective, and balanced assessment of the subject matter; nominates U.S. scientists to serve as authors; and represents the United States at IPCC meetings. DOS also works with other agencies in promoting international cooperation in a range of bilateral and multilateral science initiatives and partnerships.

Department of Transportation

The Department of Transportation (DOT) coordinates with USGCRP and its participating agencies to inform transportation system mitigation and resilience solutions. DOT initiatives to improve the resilience of the U.S. transportation sector include:

- The Federal Highway Administration (FHWA) and the Federal Transit Administration (FTA) are working with States, public transportation agencies, and metropolitan areas to increase the health and longevity of the Nation's Highways and public transportation systems, respectively, through an ongoing program of assessing vulnerabilities; considering resilience in the transportation planning process; incorporating resilience in asset management plans; addressing resilience in project development and design; and optimizing operations and maintenance practices.
- The Maritime Administration (MARAD) Ports Team is scoping a framework for a proposed asset management tool called the "Waterfront Asset Management Tool" (WFAM) for domestic port planning. This proposed asset management tool would assist public and private ports with tools to establish risk-based asset management plans to prioritize maintenance dollars and provide justification for spending scarce funding for maintenance and/or resiliency priorities.
- The Office of the Assistant Secretary for Research and Technology (OST-R) is working in partnership with FHWA and DOT's Office of Intelligence, Security, and Emergency Response to ensure that the costs and benefits of resilience are incorporated into the transportation infrastructure planning process. The goal is to develop nationally replicable modelling tools capable of estimating the regional-scale impacts of natural and man-made disasters on the transportation system. These tools will enhance pre-event planning and disaster recovery capabilities.

Environmental Protection Agency

The core purpose of the Environmental Protection Agency's (EPA's) global change research program is to develop scientific information that supports policy makers, stakeholders, and society at large as they respond to climate change and associated impacts on human health, ecosystems, and socioeconomic systems. EPA's research is driven by the Agency's mission and statutory requirements, and includes: (1) improving scientific understanding of global change effects on air quality, water quality, ecosystems, and human health in the context of other stressors; (2) assessing and defining adaptation options to effectively prepare for and respond to global change risks, increase resilience of human and natural systems, and promote their sustainability; and (3) developing an understanding of the potential environmental and human health impacts of GHG emission reduction technologies and approaches to inform sustainable mitigation solutions. EPA Program Offices and Regions leverage this research to support mitigation and adaptation decisions, as well as inform communication with external stakeholders and the public.

EPA relies on USGCRP to develop high-quality scientific models, data, and assessments to advance understanding about physical, chemical, and biological changes to the global environment and their relation to drivers of global climate change. Satellite and other observational efforts conducted by USGCRP agencies are crucial to supporting EPA's efforts to understand how land use change, population change, climate change, and other global changes are affecting ecosystems and the services they provide. EPA's global change research applies and extends these results using regional and local air quality, hydrology, and sea level rise models to better understand the impacts of climate change to specific human health and ecosystem endpoints. These connections enable local, regional, and national decision-makers to develop and implement strategies to protect human health and the environment. In turn, EPA's research provides USGCRP agencies with information and understanding about the connections between global change and impacts at local, regional, and national scales, as well as how mitigation and adaptation actions may influence global changes.

EPA's research informs approaches to prepare for, adapt to, and minimize the impacts of climate change, including extreme weather events, wildfire, and rising sea levels, and their impacts on human health and well-being and social and economic systems. Other EPA activities include applying long-term datasets, analytical tools, and models to examine and communicate observed climate change indicators and project impacts and economic damages associated with global mitigation scenarios. EPA's technical assistance and analytical expertise supports state and local decision-makers seeking to identify, prioritize, and implement adaptation work within their environmental programs.

National Aeronautics and Space Administration

NASA's global change activities span the entire Earth Science Division, from satellite observations and technology development to research and analysis that help inform real-life applications of our science. These program elements advance our capacity to observe and explore the interactions among the major components of the Earth system—including the atmosphere, ocean, land, ice, and ecosystems—and to distinguish between natural and human-induced causes and consequences of change.

As of April 2020, NASA's portfolio included 21 on-orbit missions, whose combined measurements enhanced our understanding of our changing planet. These included new satellite missions and recently launched or newly selected instruments aboard the International Space Station. Several of these came through NASA's Earth Venture portfolio, which consists of science-driven, competitively selected, cost-capped missions. In addition, NASA has made significant use of its airborne platforms and sensors together with surface-based measurements in targeted campaigns.

In tandem with these missions and measurements, NASA supports applications projects to extend the societal benefits of its research, technology, and spaceflight programs to the broader public. These include the development and transition of user-defined tools for decision support for water resources, health and air quality, ecological forecasting, disasters, food security, and more. Moreover, NASA's Earth Science Technology Office funds, develops, and demonstrates a broad range of cutting-edge technologies to enable new capabilities and reduce costs, risks, and development times for new Earth science instruments. NASA Earth science satellite data are made widely and freely available through the Earth Science Data System.

To help us understand Earth's changing atmosphere, NASA recently launched the Orbiting Carbon Observatory 3 (OCO-3) aboard the ISS, as well as the Hyper-Angular Rainbow Polarimeter (HARP) and the Compact Infrared Radiometer in Space (CIRiS), small U-Class satellites (also known as CubeSats). OCO-3 uses the vantage point of the ISS to focus on regional sources and sinks of carbon dioxide (CO_2), contributing to the global CO_2 measurements taken by its predecessor, OCO-2. The HARP CubeSat collects information about atmospheric aerosols around which cloud nuclei can form, and the CIRiS CubeSat will help measure the optical and physical properties of clouds, land, and sea surface temperatures, as well as Earth's radiation budget.

In addition to these space-based projects, NASA also recently completed two suborbital airborne campaigns to help study our atmosphere: the Cloud, Aerosol and Monsoon Processes Philippines Experiment ($CAMP^2Ex$), and the Fire Influence on Regional to Global Environments Experiment - Air Quality (FIREX-AQ). $CAMP^2Ex$ and FIREX-AQ focused on regional processes in the Philippines and the western and southeastern United States, respectively. For $CAMP^2Ex$, NASA collaborated with the Naval Research Laboratory and Manila Observatory to investigate cloud formation in the western Philippines, one of the world's most unpredictable geographic regions for weather and climate modeling. For FIREX-AQ, NASA collaborated with NOAA to investigate the effect of wildfire and prescribed burns on atmospheric chemistry over the United States.

NASA is also planning for new missions in the near future to augment our understanding of the atmosphere. Upcoming launches include the Sentinel-6 Michael Freilich satellite to continue measurements of sea surface height (altimetry), together with partners in Europe and NOAA; the Landsat 9 satellite to continue the multi-decade record of land surface measurements with the U.S. Geological Survey; and the and Surface Water Ocean Topography (SWOT) satellite to continue and enhance measurements of freshwater and oceans in partnership with France and with contributions from Canada and the UK.

In the past year, major mission-related milestones have included the following:

- NASA selected the Geosynchronous Littoral Imaging and Monitoring Radiometer (GLIMR) instrument to help understand Earth's changing land and ecosystems. GLIMR will be mounted on a NASA-selected platform for launch in the 2026–2027 timeframe and will provide unique biological, chemical, and ecological observations of coastal waters within the Gulf of Mexico, portions of the southeastern United States, and the Amazon River Plume.
- NASA confirmed the Geostationary Carbon Observatory (GeoCarb) mission. GeoCarb is set to launch in 2022 and will provide observations of column CO_2, carbon monoxide (CO), and methane (CH_4) across North America, along with measurements of solar-induced fluorescence over the Western Hemisphere.
- NASA also identified a launch opportunity for the Tropospheric Emissions: Monitoring of Pollution (TEMPO) instrument, which is expected to occur in 2022. TEMPO is designed to measure air quality over North America in unprecedented detail during daylight hours.

National Science Foundation

The National Science Foundation (NSF) addresses global change issues through investments that advance frontiers of knowledge, provide state-of-the-art instrumentation and facilities, develop new analytical methods, and enable cross-disciplinary collaborations while also cultivating a diverse, highly trained workforce and developing educational resources. In particular, NSF global change programs support the research and related activities to advance fundamental understanding of physical, chemical, biological, and human systems and

the interactions among them. The programs encourage interdisciplinary approaches to studying Earth system processes and the consequences of change, including how humans respond to changing environments and the impacts on ecosystems and the essential services they provide. NSF programs promote the development and enhancement of models to improve understanding of integrated Earth system processes and to advance predictive capability. NSF also supports fundamental research on the processes used by organizations and decision makers to identify and evaluate policies for mitigation, adaptation, and other responses to the challenge of a changing and variable environment. Long-term, continuous, and consistent observational records are essential for testing hypotheses quantitatively and are thus a cornerstone of global change research. NSF supports a variety of research observing networks that complement, and are dependent on, the climate monitoring systems maintained by its sister agencies.

NSF regularly collaborates with other USGCRP agencies to provide support for a range of multi-disciplinary research projects and is actively engaged in a number of international partnerships.

Smithsonian Institution

Within the Smithsonian Institution (SI), global change research is primarily conducted at the National Air and Space Museum, the National Museum of Natural History, the National Zoological Park, the Smithsonian Astrophysical Observatory, the Smithsonian Environmental Research Center, and the Smithsonian Tropical Research Institute. Research is organized around themes of atmospheric processes, ecosystem dynamics, observing natural and anthropogenic environmental change on multiple time scales, and defining longer-term climate proxies present in the historical artifacts and records of the museums as well as in the geologic record. Most of these units participate in the Smithsonian's Global Earth Observatories, examining the dynamics of forests (ForestGEO, formerly SIGEO) and coastal marine habitats (MarineGEO) over decadal time frames.

The Smithsonian also brings together researchers from around the Institution to focus on joint programs aimed at estimating volcanic emissions, understanding and sustaining biodiversity, monitoring animal migrations, characterizing working landscapes and seascapes, or studying emerging infectious diseases in wildlife and humans. Smithsonian paleontological research documents and interprets the history of terrestrial and marine ecosystems from 400 million years ago to the present. Other scientists study the impacts of historical environmental change on the ecology and evolution of organisms, including humans. Archaeobiologists examine the impact of early humans resulting from their domestication of plants and animals, creating the initial human impacts on planetary ecosystems.

These activities are joined by related efforts in the areas of history and art, such as the Center for Folklife and Cultural History, the National Museum of the American Indian, the Anacostia Community Museum, the National Museum of African American History and Culture, and the Cooper Hewitt Museum of Design to examine human responses to global change, within communities, reflected in art and culture, food, and music. Finally, Smithsonian outreach and education programs expand our scientific and social understanding of processes of change and represents them in exhibits and programs, including at the history and art museums of the Smithsonian. USGCRP funding enables the Smithsonian to leverage private funds for additional research, education, and outreach programs on these topics.

U.S. Agency for International Development

The U.S. Agency for International Development (USAID) carries out climate change and development work in four main areas: energy, sustainable landscapes, climate resilience, and climate risk management. USAID supports global research and analysis and partners bilaterally with dozens of countries to build capacity, address governance, and create the legal and regulatory environment needed to address climate change and development. This work is integral to helping countries pursue economic growth, stability, and self-reliance.

***Energy*:** USAID helps partner countries build strong energy sectors that can attract private investment and power global economic and social development. USAID's efforts support least-cost modern energy solutions. In many countries, renewable energy is now the least-cost solution that maximizes development impact.

***Sustainable landscapes*:** USAID supports research on estimating and accounting for land-based carbon stocks and greenhouse gas fluxes, and on governance and finance in the land sector, all with a focus on developing countries. USAID also supports partner countries in meeting their commitments to reduce land-based greenhouse gas emissions, often through activities that promote conservation, restoration, and sustainable use of forests, agriculture, and other lands. By improving landscape management, USAID helps to curb destruction and degradation, improve livelihoods, and increase resilience.

Climate resilience: USAID works with partner countries to build climate resilience and disaster preparedness to weather and climate-related shocks and stresses such as droughts, floods, and shifting rainfall patterns. Improved weather and climate information, informed land use planning, and smart infrastructure design are some ways communities can prepare for these risks and avoid setbacks. Thinking ahead and proactively managing risks help sustain livelihoods and maintain critical services, reducing the need for costly disaster response.

Climate risk management (CRM): CRM is an internal USAID practice to assess, address and manage climate risk in new strategies, projects, and activities across USAID's development portfolio, safeguarding U.S. investments through informed decision-making.

With over seventy overseas missions, USAID enables decision-makers to apply high-quality climate information to their decision-making and enables countries to accelerate their transition to climate resilient, sustainable economic development. USAID achieves these objectives through direct programming and integration of climate change adaptation and mitigation activities into the broader development portfolio.

USAID leverages scientific and technical resources from across the U.S. Government, private sector partners, and nongovernmental organizations and science institutes to develop and implement low-emissions development strategies, creating policy frameworks for market-based approaches to emission reduction and energy sector reform, promoting sustainable management of agricultural lands and forests, protecting biodiversity, and mainstreaming adaptation into development activities in countries most at risk to advance resilient and sustainable development.